Nano zinc Supplementation Compared with Other Zinc Forms: Effects on Growth Performance, Serum Concentrations, and Economic Evaluation in Broiler Chickens

Hamada S. Saber[1], Heba A. Alian [2*]

[1] *Department of Animal Production, Faculty of Agriculture, Suez Canal University, Ismailia (41522), Egypt.*

[2] *Department of Nutrition and Clinical Nutrition, Faculty of Veterinary Medicine, Suez Canal University, Ismailia (41522), Egypt.*

** Corresponding author: Heba A. Alian , Email: hoba.alian15@gmail.com, heba.alian@vet.suez.edu.eg, Tel: (002) 01205195133, ORCID: 0000-0002-7563-2016*

Abstract

The current study's aim was to assess how different zinc sources affected the broilers' growth performance, serum concentrations and economic evaluation. One-day-old "Cobb" broiler chicks (n = 192) with an average initial body weight of 44.10 g were randomly distributed into 6 groups. The 1st, 2nd, and 3rd groups were supplied with inorganic zinc oxide, inorganic zinc sulphate monohydrate, and organic zinc methionine, respectively, at a level of 100 mg Zn/kg diet. The 4th, 5th, and 6th groups were supplied with nano zinc oxide (NZnO) at a level of 20, 10, and 5 mg Zn/kg diet, respectively. The study exposed that NZnO at a level of 5 mg Zn/kg (G6) achieved a significant improvement *($P < 0.05$)* in final body weight, cumulative body weight gain, feed conversion ratio, and feed efficiency. NZnO (G6) increased superoxide dismutase activity (SOD) and HDL (high-density lipoprotein) levels either significantly *($P < 0.05$)* compared to G1, G2, G3, and G4 or numerically with G5. Adding NZnO lessens blood serum malondialdehyde (MDA), alanine aminotransferase (ALT), aspartate aminotransferase (AST), and creatinine levels. Nano zinc oxide in G5 and G6 significantly achieved the best results in economic efficiency enhancement *($P < 0.05$).* The nano zinc oxide groups achieved the best performance, boosted antioxidant activity, enhanced lipid profiling, and improved liver and kidney functions. The positive results were more noticeable in the G6. Therefore, applying NZnO (5 mg Zn/kg diet) is a new promising feed additive in the broiler industry.

Keywords: Antioxidant, Broiler, Economic, Nano zinc, Performance.

1. Introduction

The Food and Agriculture Organization ***(FAO, 2009)*** documented that chicken meat is a promising option to satisfy global demand. It is the second most popular source of protein consumed globally. Therefore, one of the primary goals of the public and private sectors is to increase poultry productivity. A wide range of additives are added to poultry diets. Their main purposes are to improve feed utilization, prevent disease, and enhance the efficacy of the bird's growth and/or laying performance ***(Ayalew et al., 2022).*** Zinc (Zn) nutrition has grown to be a major concern for many experts, especially in the field of poultry production. Zn is a vital trace mineral that has many biological processes in livestock, notably in rapidly growing chickens ***(Zampiga et al., 2021).*** It is a critical part of more than 300 distinct enzymes implicated in synthesizing and degrading lipids, proteins, carbohydrates, and nucleic acids. Some of these enzymes include alcohol dehydrogenase, aldolase, alkaline phosphatase (ALP), lactate dehydrogenase (LDH), superoxide dismutase (SOD), and RNA and DNA polymerases ***(Kumar et al., 2023).*** Owing to its inexpensiveness, zinc is typically supplied to chicken diets in inorganic sources such as oxides, sulfates, and carbonates. However, the bioavailability of inorganic zinc is significantly lower in mono gastric animals ***(Liu et al., 2020).*** Most broiler diets based on grains contain phytic acid, which combines with inorganic zinc, resulting in a delay in the absorption of zinc and calcium by the gastrointestinal tract. This, in turn, inhibits the tissues' ability to uptake zinc ***(McDowell, 2003).*** This issue creates an opportunity to find higher bioavailable zinc forms. That may lessen the supplemental level of Zn to the diet ***(Sahin et al., 2005).*** It is possible to substitute organic sources for inorganic trace minerals to decrease over supplementation and excretion ***(Zhu et al., 2019).*** Organic minerals do not interact with phytate because they do not have the free divalent cations required for chelation in the intestine. Since organic zinc sources, such as zinc proteinate, zinc lysine, and zinc methionine, have been demonstrated to have better bioavailability than inorganic zinc sources. They can be substituted for inorganic zinc sources without having an adverse effect on the environment or poultry production ***(Behjatian Esfahani et al., 2021).*** Recently, nanotechnological applications have been widely used to improve trace elements' efficiency in animal diets. Therefore, to improve chicken productivity, researchers have to use nano-form additives in broiler diets ***(Hassan et al., 2020).*** Among these nanotechnology approaches, nano zinc oxide (NZnO) is notable for its high adsorbing capacity and catalytic efficacy. It is a unique prepared trace mineral ranging in size from 1 to 100 nm. Both at lower and higher levels, it has demonstrated a different impact on animal performance. In addition to being greatly bioavailable, studies have already shown that nano zinc has numerous other benefits, including growth promotion, antimicrobial activity, supporting immunity, and modulating of animal reproduction. It can be utilized at lower dosages, return better results than traditional zinc forms, and consequently contribute to lessening environmental contamination ***(Leareng et al., 2020).*** Therefore, the current study aimed to assess how various dietary zinc sources affected the broiler chickens' growth performance, economic evaluation, and serum concentrations.

2. Materials and methods

2.1. Experimental birds, design, and diets.

The Suez Canal University Faculty of Agriculture's Animal Care and Use Committee has authorized all procedures, as indicated by approval number (4/2024). 192 one day (Cobb) broiler chicks, unsexed, were purchased from a commercial hatchery (Ismailia Misr Poultry Company). Chicks randomly distributed into 6 dietary treatments with 4 replicates of 8 chicks. Birds in the 6 treatments were given a corn-soybean-based diet for 35 days. The 1st, 2nd, and 3rd groups were supplied with inorganic zinc oxide, inorganic zinc sulphate monohydrate, and organic zinc methionine, respectively, at a level of 100 mg Zn/kg diet. The 4th, 5th, and 6th groups were supplied with nano zinc oxide at a level of 20, 10, and 5 mg Zn/kg diet, respectively. The experimental basal diet was prepared according to ***NRC (1994)*** to satisfy the nutrient needs of chicks. The formulation and chemical analysis (calculated and determined according to ***AOAC (2002)*** of the basal diets are given in Table 1. All birds were kept in a climate-controlled house with continuous lighting and unrestricted access to mashed meals and water. For the first three days, the house's temperature was maintained between 32 and 34 °C; then, it was lowered by 2 to 3°C per week until 3 weeks of age. There were electric fans for ventilation. Every chick was vaccinated and kept in good hygiene, according to the routine preventive vaccination schedule.

2.2. Preparation of nano zinc oxide

The process is carried out following the stated technique by ***(Kumar et al., 2013).*** 1500 ml of deionized water was used to dissolve 431.31 g of zinc sulfate heptahydrate (1M). 122.40 g of sodium hydroxide (2 M) was then added dropwise while being stirred magnetically. Following the addition, stirring persisted for a full twelve hours. The precipitates underwent multiple filtrations and were washed with clean water. The precipitate was dried for 30 minutes at 100°C and calcined for two hours at 500°C. An X-ray diffractometer (XRD, X′ Pert PRO) was used to examine the crystalline and phase structures of the synthesized ZnO. The diffraction charts and relative intensities are obtained and matched with ICDD files **(Fig. 1)**. Transmission electron microscopy (TEM, JEOL JEM-2100) was used to identify the size and shape. TEM images of ZnO show nanoparticles with a mean particle size of 34 nm. Most of the individual particles in the ZnO nanoparticle TEM micrograph are between 19 and 65 nm in size **(Fig. 2)**. The characterization was done at the Central Lab, Agricultural Research Center, Egypt.

2.3. Studied parameters.

2.3.1. Growth performance

Body weight (BW) and weight gain (WG) were determined weekly for each experimental unit (pen). Feed intake (FI), feed conversion ratio (FCR), and feed efficiency (FE) were also calculated weekly. Mortality was recorded daily and calculated as a percentage of the total number of birds. The performance index (PI) was calculated as body weight (kg)/ FCR × 100, and the European efficiency index (EEI) was calculated as 100 × (body weight (kg) × livability (%)/ (age (days) × FCR) and the protein efficiency ratio (PER) was determined as weight gain (g)/protein intake (g). All these parameters were calculated according to ***Alian et al. (2023).***

2.3.2. Serum biochemical parameters

During the slaughter process, blood samples were taken and placed in sterile tubes without the use of an anticoagulant. The samples were centrifuged for ten minutes at 4ºC at 5000 rpm. The collected sera samples were stored at -20 °C in a deep freezer. Superoxide dismutase (SOD) activity was determined using the method explained by ***Oyanagui (1984).*** The malondialdehyde (MDA) was determined by the method indicated by ***Ohkawa et al. (1979).*** SOD and MDA contents were measured using reagent kits (Egyptian Company for Biotechnology, S.A.E, and Diamond, D-P, International) as per manufacture procedures. The cholesterol, triglycerides, high-density lipoprotein (HDL), low-density lipoprotein (LDL), total protein, albumin, globulin, A/G ratio, aspartate aminotransferase (AST), alanine aminotransferase (ALT), lactate dehydrogenase (LDH), alkaline phosphatase (ALP), creatinine, and uric acid were estimated by atomic absorption spectrophotometry using the kits purchased by (Egyptian Company for Biotechnology, S.A.E, and Diamond, D-P, International).

2.3.3. Economic evaluation

Economic efficiency (EE) was estimated according to ***El-Haliem et al. (2020).***

2.4. Statistical Analysis

The obtained data was assessed for mean, standard errors, and analysis of variance using software (SPSS, version 16, USA). The difference between the groups was deemed significant for each measurement at *(P < 0.05).* The means were compared using Duncan's multiple-range tests ***(Duncan, 1955).***

3. Results

3.1. Growth performance parameters

Our data showed that nano zinc oxide, whatever the concentration (G4, G5 & G6) achieved significant enhancement (*P < 0.05)* in final body weight and cumulative body weight gain when compared to inorganic zinc oxide (G1) and numerically to inorganic zinc sulphate monohydrate group (G2), table 2. Our data also displayed that organic zinc methionine (G3) at the level of 100 mg Zn/kg diet significantly *(P < 0.05)* improved final body weight and cumulative weight gain compared to chicks in G1 and numerically to G2. There were no statistical *(P > 0.05)* differences in the cumulative feed intake between experimental groups. The supplementation of nano zinc oxide in G5 and G6 at the level of 10 and 5 mg Zn/kg diet, respectively, significantly achieved the best results in overall FCR and FE enhancement *(P < 0.05)* in comparison to chicks in G1 and G2 and numerically to G3 and G4. Nano zinc supplemented groups (G4, G5&G6) significantly *(P < 0.05)* gave the highest performance index (PI) as compared with inorganic zinc oxide supplemented group (G1), table 3. Also, the organic zinc methionine group (G3) achieved the best PI value either significantly *(P < 0.05)* compared to the inorganic zinc oxide supplemented group (G1) or numerically to G2. Furthermore, NZnO (G6) significantly *(P < 0.05)* enhanced the European efficiency index (EEI) and protein efficiency ratio (PER) for finisher diets in contrast to chicks in G1 and numerically compared to G2, G3, G4, and G5.

3.2. Livability and mortality.

Figure 3 shows the livability and mortality rates of birds in all groups fed basal diets supplied with different sources and amounts of zinc. According to our findings, the average livability and mortality rate across the experimental groups did not vary significantly *(P > 0.05).*

3.3. Serum biochemical parameters

Table 4 presents the findings about the impact of zinc supplementation on serum biochemical parameters. Concerning the data related to the antioxidant status, it was observed that NZnO (G6) at the level of 5 mg Zn/kg diet increased SOD activity either significantly *(P < 0.05)* compared to G1, G2, G3, and G4 or numerically with G5. Moreover, nano zinc oxide in G4 and G5 at a level of 20 and 10 mg Zn/kg diet, respectively, significantly achieved the highest SOD activity in contrast to chicks of G1, G2, and G3. The highest significant increase in SOD activity was achieved in zinc methionine (G3) at a level of 100 mg Zn/kg diet compared to G1 and G2. Nano zinc oxide-supplemented groups (G4, G5, and G6) significantly *(P<0.05)* achieved the lowest levels of serum MDA compared to inorganic zinc-supplemented groups (G1 and G2). About the impact of different dietary zinc on lipid profile, it was noticed that the levels of triglycerides and cholesterol did not significantly differ among the experimental groups. Also, the G6 (5 mg Zn/kg diet) gave the highest HDL level, either significantly *(P<0.05)* compared to chicks in G1, G2, G3, and G4 and or numerically with G5. There was no statistical difference between G6 in the level of LDL compared with G5, G4, and G3. Concerning the findings related to liver function and serum enzyme activity, it was noticed that there was a significant *(P > 0.05)* elevation in total protein and A/G ratio in nano zinc supplemented groups (G4, G5, and G6) in contrast with G1. Also, G4, G5, and G6 a significant *(P > 0.05)* elevated the albumin level compared to G1, G2, and G3. The globulin level did not differ significantly (*P > 0.05*) among the experimental groups. Nano zinc supplemented groups (G4, G5, and G6) significantly *(P<0.05)* reduced the AST level compared to G1 and G2. Nano zinc oxide (G6) at the level of 5 mg Zn/kg diet significantly *(P<0.05)* reduced ALT levels compared to other zinc sources and levels. Furthermore, nano zinc oxide in G4 and G5 at a level of 20 and 10 mg Zn /kg diet, respectively, lessen the ALT level either significantly *(P<0.05)* compared to G1 or numerically with G2 and G3. The supplementation of different zinc sources did not show any significant *(P > 0.05)* effect on ALP and LDH at 35 days of age. Regarding the effect on kidney function, it was noted that G4, G5, and G6 (nano zinc oxide supplemented groups) had the lowest serum creatinine level *(P<0.05)* when compared to G1 and G2 (inorganic zinc supplemented groups at a level of 100 mg Zn/kg diet). However, no statistically significant difference *(P > 0.05)* was observed in serum uric acid levels among experimental groups.

3.4. Economical evaluation parameters.

Using nano zinc oxide whatever the concentration (G4, G5& G6) and zinc methionine (G3) at a level of 100 mg Zn/kg diet significantly *(P < 0.05)* offered the highest selling price in comparison with chicks in G1 and numerically than G2, table 5. Adding nano zinc oxide and zinc methionine resulted in significant cost savings *(P < 0.05)* in comparison to the zinc oxide group, where net revenue was 27.87, 28.17, 29.04, and 29.30 L. E in G3, G4, G5, and G6, respectively, compared to 25.23 L. E in G1. The nano zinc oxide in G5 and G6 at the level of 10 and 5 mg Zn/kg diet, respectively, significantly achieved the best results in economic efficiency enhancement *(P < 0.05)* if compared to G1 and G2 and numerically to G3 and G4.

Table (1): *Formulation and chemical analysis of the experimental basal diets.*

Ingredient (%)	Starter (0-8D)	Grower (9-18D)	Finisher (19-35D)
Yellow corn	57.00	60.50	64.90
Soybean meal	30.00	27.00	24.31
Corn gluten meal 60%	6.70	5.00	3.00
Vegetable oil	1.82	3.01	3.92
Calcium carbonate	1.24	1.07	1.00
Di calcium phosphate	1.68	1.57	1.40
Mineral premix [1]	0.25	0.25	0.25
Vitamin premix [2]	0.25	0.30	0.25
NaCl	0.40	0.60	0.37
DL-Methionine	0.23	0.21	0.28
L-Lysine	0.33	0.29	0.22
Choline chloride	0.10	0.20	0.10
Total	100	100	100
Chemical calculated values %			
Metabolizable energy (Kcal/kg)	**3001**	**3101**	**3200**
Crude protein (CP)	22.07	20.02	18.01
Lysine	1.321	1.196	1.052
Methionine	0.609	0.552	0.581
Methionine + Cystine	0.984	0.895	0.892
Calcium	0.939	0.842	0.771
A. Phosphorous	0.450	0.442	0.383
Chemical determined analysis%			
Moisture	8.72	8.92	9.05
Crude protein	21.82	19.71	18.16
Crude fiber	3.43	3.64	3.86
Ether extract	4.83	5.34	6.85
Crude ash	5.32	5.51	5.71
Nitrogen free extract	56.37	56.88	55.88

[1] Each 2 kg of minerals mixture contained: 500.000 mg choline chloride, 150.000 mg Cu, 1.000 mg I, 40.000 mg Fe, and 100.000 mg Mn. [2] Each 1 kg of vitamin mixture contained 10.000.000 IU vit. A, 5.000.000 IU vit. D3, 80.000 mg vit. E, 3.000 mg vit. K3, 3.000 mg vit. B1, 9.000 mg vit. B2, 4.000 mg vit. B6, 20 mg vit. B12, 15.000 mg pantothenic acid, 60.000 mg Nicotinic acid, 2.000 mg Folic acid, and 150 mg Biotin.

Table (2): *The growth performance parameters of broiler chicks at the end of the experimental period (35d.).*

	Group					
Parameter	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
Initial B.W. (g)	44.18 [a] ± 0.45	43.71 [a] ± 0.39	44.09 [a] ± 0.35	44.18 [a] ± 0.46	44.46 [a] ± 0.42	43.96 [a] ± 0.38
Final B.W. (g)	2100.50 [b] ± 34.34	2179.40 [ab] ± 37.79	2220.36 [a] ± 35.22	2233.86 [a] ± 37.90	2247.83 [a] ± 40.09	2248.25 [a] ± 28.17
Cumulative W.G.(g)	2056.36 [b] ± 34.40	2135.96 [ab] ± 37.82	2176.40 [a] ± 35.20	2189.80 [a] ± 38.00	2203.30 [a] ± 40.12	2204.25 [a] ± 28.24
Cumulative FI (g)	3512.45 [a] ± 14.31	3604.77 [a] ± 60.56	3623.30 [a] ± 38.38	3618.57 [a] ± 72.51	3560.10 [a] ± 32.00	3538.27 [a] ±51.38
FCR	1.70 [a] ± 0.02	1.69 [a] ± 0.02	1.66 [ab] ± 0.01	1.65 [ab] ± 0.02	1.61 [b] ± 0.01	1.60 [b] ± 0.01
FE	0.58 [b] ± 0.006	0.59 [b] ± 0.007	0.60 [a b] ± 0.007	0.60 [a b] ± 0.01	0.62 [a] ± 0.007	0.62[a] ± 0.004

Values are mean ± SE. Values in the Organic, (with different superscripts are significantly different at *P < 0.05*. G1: basal diet + Zinc Oxide, inorganic, (100 mg Zn / kg diet). G2: basal diet + Zinc sulphate monohydrate, Inorganic, (100 mg Zn / kg diet). G3: basal diet + Zinc methionine, Organic, (100 mg Zn / kg diet). G4: basal diet + Zinc oxide, Nanoparticles, (20 mg Zn / kg diet). G5: basal diet + Zinc oxide, Nanoparticles, (10 mg Zn / kg diet). G6: basal diet + Zinc oxide, Nanoparticles, (5 mg Zn / kg diet). **B.W**: Body weight, **W.G**: Weight gain, **FI**: Feed intake, **FCR**: Feed conversion ratio, and **FE**: Feed efficiency.

Table (3): *Mean values of performance index (PI), European efficiency index (EEI), protein intake, and protein efficiency ratio (PER).*

	Group					
Parameter	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
PI	123.10 [c] ± 3.31	128.86 [bc] ± 2.02	133.45 [ab] ± 2.73	135.03 [ab] ± 5.46	138.97 [ab] ± 2.30	140.29 [a] ± 1.80
EEI	329.56 [b] ±14.58	345.34 [ab] ± 15.78	357.05 [ab] ± 12.20	362.52 [ab] ± 24.54	372.61[ab] ± 18.07	388.45 [a] ± 14.70
Protein intake (starter)	35.68 [a] ± 1.28	34.43 [a] ± 1.21	35.02 [a] ± 0.90	34.27 [a] ± 0.63	33.40 [a] ± 1.05	34.38 [a] ± 1.14
PER (starter)	2.90 [a] ± 0.21	3.09 [a] ± 0.26	3.17 [a] ± 0.10	3.27 [a] ± 0.02	3.38 [a] ± 0.07	3.34 [a] ± 0.15
Protein intake (grower)	216.85 [a] ± 2.51	217.85 [a] ± 1.46	216.06 [a] ±1.47	218.40 [a] ± 0.59	219.25 [a] ± 2.08	218.65 [a] ± 1.87
PER (grower)	3.23 [a] ± 0.06	3.21 [a] ± 0.04	3.24 [a] ± 0.03	3.24 [a] ± 0.007	3.29 [a] ± 0.01	3.30 [a] ± 0.05
Protein intake (finisher)	407.88 [a] ± 5.02	424.62 [a] ± 10.43	429.07 [a] ± 5.59	426.73 [a] ± 13.06	416.16 [a] ± 6.90	411.97 [a] ±7.05
PER (finisher)	3.06 [b] ± 0.06	3.12[ab] ± 0.03	3.18 [ab] ± 0.03	3.19 [ab] ± 0.09	3.28 [ab] ± 0.04	3.29 [a] ± 0.01

Values are mean ± SE. Values in the same row with different superscripts are significantly different at *P < 0.05*.

Table (4): *Serum biochemical parameters of broiler chicks at the end of the experimental period (35d.).*

	Group					
Parameter	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
SOD (U/ml)	155.09 ^{d} ± 1.61	154.33 ^{d} ± 2.69	162.46 ^{c} ± 1.84	168.35 ^{b} ± 1.86	171.45 ^{ab} ±2.07	174.81^{a} ± 1.94
MDA (nmol/ml)	3.01 ^{a} ± 0.04	3.04 ^{a} ± 0.03	2.90 ^{ab} ± 0.05	2.77 ^{bc} ±0.06	2.71 ^{c} ± 0.06	2.60 ^{c} ± 0.08
Cholesterol (mg/dL)	150.92 ^{a} ± 10.22	161.39 ^{a} ± 2.05	159.68 ^{a} ± 2.18	159.14 ^{a} ±2.74	158.70 ^{a} ± 2.30	158.34 ^{a} ± 2.32
Triglycerides(mg/dL)	67.07 ^{a} ±1.66	67.18 ^{a} ± 1.22	65.68 ^{a} ± 1.75	64.65 ^{a} ±1.29	64.91^{a} ± 1.46	63.91 ^{a} ± 1.58
HDL (mg/dL)	57.12 ^{c} ± 1.59	59.45 ^{bc} ± 1.38	59.13 ^{c} ± 1.18	60.74 ^{bc} ± 1.25	63.86 ^{ab} ± 2.03	66.20 ^{a} ± 1.50
LDL (mg/dL)	41.73 ^{d} ± 0.85	44.02 ^{cd} ± 1.00	44.60 ^{bcd} ± 1.15	44.92 ^{bc} ± 1.02	48.19 ^{a} ± 0.92	47.40 ^{ab} ± 0.89
Total protein(g/dL)	3.57 ^{b} ± 0.08	3.71^{ab} ± 0.07	3.70 ^{ab} ± 0.06	3.85 ^{a} ± 0.06	3.83 ^{a} ± 0.07	3.83 ^{a} ± 0.05
Albumin (g/dL)	1.51 ^{b} ± 0.04	1.64 ^{b} ± 0.05	1.65 ^{b} ± 0.05	1.89 ^{a} ±0.07	1.89 ^{a} ± 0.08	1.94 ^{a} ± 0.05
Globulin (g/dL)	2.06 ^{a} ± 0.08	2.06 ^{a} ± 0.10	2.05 ^{a} ± 0.08	1.96 ^{a} ± 0.08	1.94 ^{a} ± 0.09	1.89 ^{a} ± 0.08
"A/G ratio"	0.75 ^{c} ± 0.03	0.85 ^{bc} ± 0.06	0.84 ^{bc} ± 0.06	1.01 ^{ab} ±0.08	1.04 ^{ab} ± 0.10	1.07 ^{a} ± 0.07
AST(U/l)	173.31 ^{a} ± 1.68	172.47 ^{a} ± 1.94	169.05 ^{ab} ±1.39	166.05 ^{b} ± 2.02	165.83 ^{b} ± 2.53	164.15 ^{b} ±2.12
ALT (U/l)	7.66 ^{a} ± 0.15	7.23 ^{ab} ± 0.18	7.45 ^{ab} ± 0.14	6.94 ^{b} ± 0.19	6.95 ^{b} ± 0.17	5.11 ^{c} ± 0.25
ALP (U/L)	330.85 ^{a} ±3.98	326.96 ^{a} ± 2.68	323.38 ^{a} ± 2.99	319.75 ^{a} ±3.10	322.94 ^{a} ± 4.51	322.82 ^{a} ± 3.84
LDH (U/L)	3112.50 ^{a} ± 49.66	3114.56 ^{a} ± 51.40	3128.50 ^{a} ± 47.39	3135.93 ^{a} ± 35.99	3196.75 ^{a} ± 46.65	3212.00 ^{a} ±44.09
Creatinine (mg/dL)	3.06 ^{a} ± 0.03	3.01 ^{ab} ± 0.07	2.84 ^{bc} ±0.05	2.70 ^{cd}± 0.07	2.59 ^{d} ± 0.07	2.60 ^{d} ± 0.08
Uric acid (mg/dL)	8.41 ^{a} ± 0.19	8.45 ^{a} ± 0.20	8.42 ^{a} ± 0.21	8.10 ^{a} ± 0.16	8.01 ^{a} ± 0.15	8.01 ^{a} ± 0.12

Values are mean ± SE. Values in the same row with different superscripts are significantly different at $P < 0.05$. **SOD: Superoxide dismutase, MDA**: malondialdehyde, **HDL**: high-density lipoprotein, **LDL**: low-density lipoprotein, **AST**: aspartate aminotransferase, **ALT**: alanine aminotransferase, **LDH**: lactate dehydrogenase, and **ALP**: alkaline phosphatase.

Table (5): *The economical evaluation of broiler production as affected by different dietary zinc treatments.*

	Group					
Parameter	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
Number of chicks	32.00	32.00	32.00	32.00	32.00	32.00
Price/chick (LE)	4.50	4.50	4.50	4.50	4.50	4.50
Final wt. (g)	2101.15 ^{b} ± 31.15	2176.93 ^{ab} ± 24.54	2220.79 ^{a} ± 28.73	2231.70 ^{a} ± 60.37	2246.51 ^{a} ± 23.42	2249.76 ^{a} ± 20.44
Feed intake /chick (g)	3512.45 ^{a} ± 14.31	3604.77 ^{a} ± 60.56	3623.30 ^{a} ± 38.38	3618.57 ^{a} ± 72.513	3560.10 ^{a} ± 32.00	3538.27 ^{a} ± 51.38
Feed cost /chick (LE) [1]	23.98 ^{a} ± 0.09	24.62 ^{a} ± 0.41	24.74 ^{a} ± 0.26	24.71 ^{a} ± 0.49	24.31 ^{a} ± 0.21	24.16 ^{a} ± 0.35
management /chick (LE)	5.00	5.00	5.00	5.00	5.00	5.00
Feed additive cost /chick	0.105 ^{a} ± 0.0004	0.036 ^{e} ± 0.0006	0.058 ^{c} ± 0.0006	0.094 ^{b} ± 0.001	0.046 ^{d} ± 0.0004	0.023 ^{f} ± 0.0003
Total cost /chick (LE) [2]	33.59 ^{a} ± 0.09	34.15 ^{a} ± 0.41	34.30 ^{a} ± 0.26	34.30 ^{a} ± 0.49	33.86 ^{a} ± 0.21	33.68 ^{a} ± 0.35
Selling price (LE)	58.83 ^{b} ± 0.87	60.95 ^{ab} ± 0.68	62.18 ^{a} ± 0.80	62.48 ^{a} ± 1.69	62.90 ^{a} ± 0.65	62.99 ^{a} ± 0.57
Net revenue (LE) [3]	25.23 ^{c} ± 0.79	26.79 ^{bc} ± 0.48	27.87 ^{ab} ± 0.65	28.17 ^{ab} ± 1.32	29.04 ^{ab} ± 0.53	29.30 ^{a} ± 0.40
Economic efficiency [4]	75.10 ^{c} ± 2.23	78.47 ^{bc} ± 1.54	81.25 ^{abc} ± 1.76	82.07 ^{ab} ± 3.28	85.76 ^{a} ± 1.47	87.00 ^{a} ± 1.37

Values are mean ± SE. Values in the same row with different superscripts are significantly different at $P < 0.05$. [1] Price of one kg of recommended diet = 10.00 LE. [2] = Price of chick + management + feed cost + additive. [3] = Selling price – total cost. [4] = Net revenue / total cost x 100

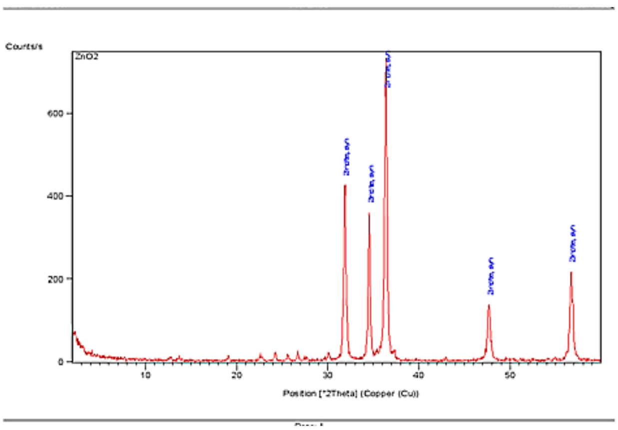

Fig 1. XRD pattern of NZnO.

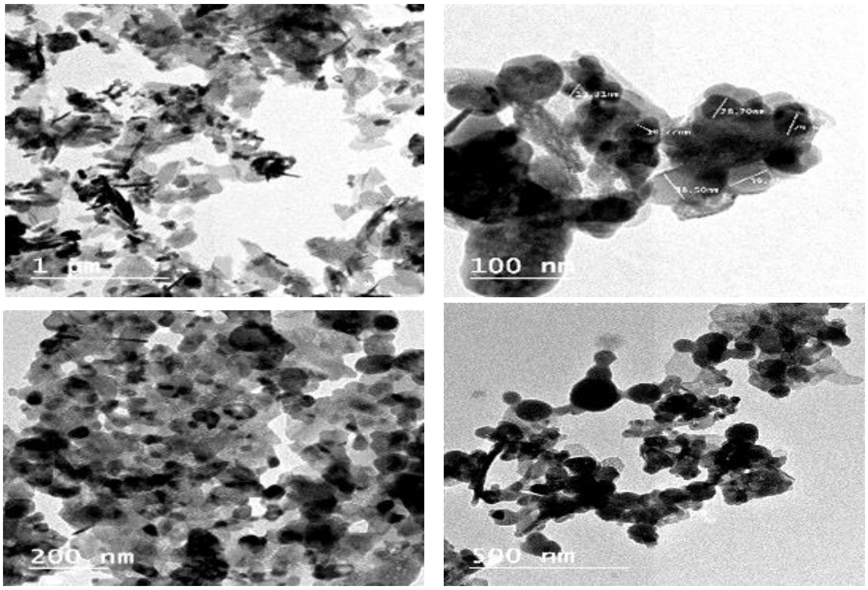

Fig 2. The TEM image of nano zinc oxide (NZnO).

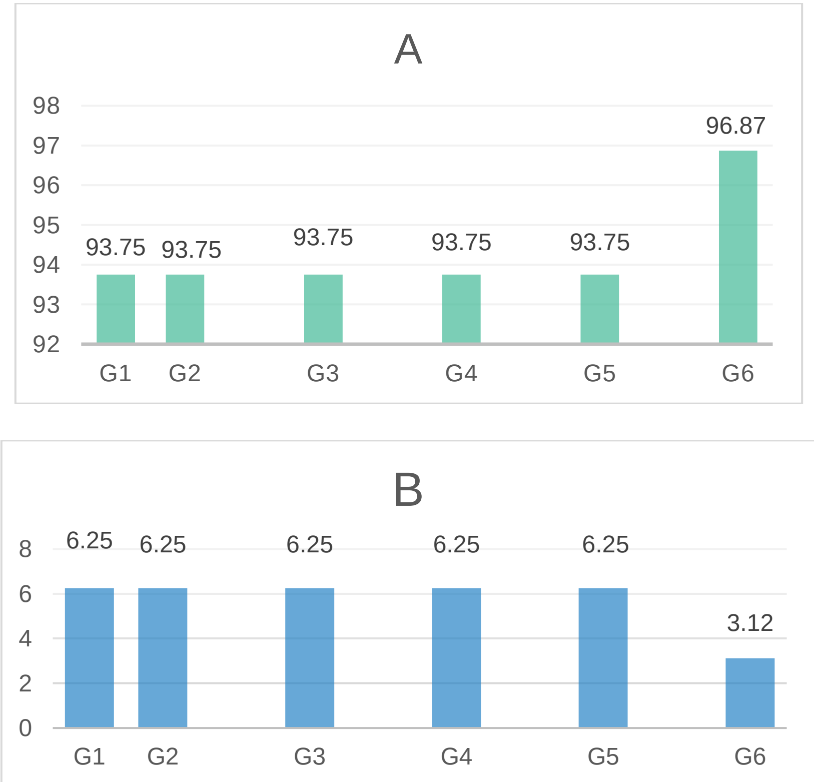

Fig 3. Livability (A) and mortality (B)% in the experimental groups

4. Discussion

The enhancement of nano zinc on growth performance regardless of concentration could be attributed to the unique features of zinc in nanoform. Generally, zinc is a vital nutrient that plays a wide range of roles in the metabolism of proteins, carbs, and fats, as well as in the synthesis and release of hormones, including growth hormone., insulin, and sex hormone; hence, it may have an impact on the productivity and reproductive abilities of animals. Also, zinc is a compound of DNA-binding proteins that controls the expression of genes and contributes to the synthesis of proteins and nucleic acids. ***(McDowell, 2003).*** Moreover, ***Hafez et al. (2017)*** stated that the improvement in growth could be ascribed to the function of NZnO in augmenting the intestinal absorptive capacity by enhancing the length and depth of the crypt's mucosal and villi. All these features augment the role of nano zinc oxide and lead to improved body health and, consequently, the growth parameters of broilers. The same trend was declared by ***Zhao et al. (2014);*** they found that, in comparison to 60 mg/kg ZnO, nano zinc oxide at levels of 20 and 60 mg/kg diet could boost BW, WG, and feed efficiency. Furthermore, ***Joshua et al. (2016)*** verified that the use of nanoelements (zinc, copper, and selenium) can improve the post-hatch performance of broiler chickens, including body weight, weight gain, and feed conversion, and that these elements are safe for the embryo. ***Mahmoud et al. (2020)*** showed that 10 ppm NZnO considerably increased the feed conversion and body weight gain compared to the control (0 ppm). In addition, ***Alian et al. (2023)*** observed that nano zinc (40 mg/kg) significantly enhanced the FCR, WG, and ADG (Average daily gain) of broilers.

Our findings were contradicted by ***Rossi et al. (2007),*** who found no variation in ADG between broilers fed 0 and 15– 60 mg Zn/kg feed. ***Ramiah et al. (2019)*** showed that the broilers' body weight was unaffected by NZnO supplementation at doses of 40, 60, and 100 mg Zn/kg feed. ***Bami et al. (2020)*** found that broiler growth features were unaffected by using nano Zn sources (25 and 50 ppm). The average values of crude protein, calorie conversion ratio, body weight growth, and final body weight did not differ statistically significantly between treatment groups that received 100, 80, 60, 40, and 20 mg NZnO/kg of feed ***(El-Haliem et al., 2020). Asheer et al. (2018) o***bserved that substituting nano zinc oxide at levels of 25, 50, 75, and 100% for traditional zinc in a broiler feed did not significantly affect the broiler's weekly FCR. ***Eskandani et al. (2021)*** claimed that the ADG, ADFI, and FCR of broilers in the starting phase were not significantly affected by 30, 50, 70, and 90 ppm of nano Zn oxide addition. Variations in feed intake, bird strain, sources and quantities of zinc, and the length of the experiment could all be contributing factors to the discrepancy ***(Alian et al., 2023).***

There was an improvement in the BW and WG of broilers because of organic zinc methionine supplementation (100 mg Zn/kg diet) compared to conventional inorganic zinc sources. This is due to the inorganic zinc in the intestine linked to phytic acid. However, the lack of free divalent cations required for intestinal chelation prevented organic zinc sources from combining with phytates, resulting in increased absorption and utilization ***(McDowell, 2003).*** This is parallel to several reports that state that organic zinc has a higher bioavailability and will have a greater impact on broiler performance ***(Salim et al., 2012).*** The data matched those of ***El-Husseiny et al. (2012)*** who found that BWG was enhanced by feeding broilers' diets with 50% organic forms of zinc and magnesium (Mn), and copper (Cu) of their requirements. ***Liu et al. (2013) c***laimed that when compared to Zn sulfate, chicks fed with Zn proteinate (10, 20, 40, or 80 ppm) displayed higher WG. Moreover, ***Olukosi et al. (2018)*** revealed that broiler performance was improved more by organic zinc and copper than by sulfate zinc and copper. The group that received a 50 mg/kg diet had a significantly higher body weight, indicating the effectiveness of organic zinc ***(Chand et al., 2020).***

On the other hand, it was discovered that feeding broilers with organic zinc source at doses of 15, 30, 45, or 60 ppm did not impact their BWG ***(Rossi et al., 2007). Bun et al. (2011)*** discovered that the growth traits were unaffected by Zn methionine hydroxyl at 0, 20, 40, and 60 mg/kg diet. Furthermore, ***Sunder et al. (2013)*** demonstrated that taking supplements containing organic zinc and magnesium did not influence weight increase or body weight. ***Kakhki et al. (2017)*** noted that broiler hens fed diets enhanced with 60 or 120 mg Zn/kg of zinc methionine (Zn-Met) did not exhibit any variations in ADG. The lack of effect in terms of the performance of birds might result from using different types and dosages of zinc in the feeds of broiler chickens.

Our findings showed that the cumulative FI did not differ statistically between the zinc-supplemented groups. This is matches with that mentioned by ***Sunder et al. (2013)*** who revealed that 40, 80, and 160 ppm of organic zinc did not influence the FI of broiler chicks. Moreover, broiler chicks received diets enriched with Zn 60 or 120 mg/kg, as Zn-Me did not exhibit any variations in ADFI ***(Kakhki et al., 2017).*** Finally, dietary nano Zn treatments (30, 50, 70, and 90 ppm) had no significant impact on ADFI in the starter phase compared to $ZnSO_4$ and Zn amino acid complexes (70 ppm) ***(Eskandani et al., 2021).*** However, ***Jahanian et al. (2008)*** stated that the average feed intake was decreased *(P< 0.001)* when the Zn level was increased from 80 to 120 mg/kg diet. The lack of significant impact on feed intake in the groups receiving NZnO suggests that the zinc levels in the control diet were adequate for the growth of the birds.

Nano zinc oxide (G4, G5, and G6) and organic zinc methionine group (G3) significantly achieved the highest performance index compared to zinc oxide (G1), which was greatly matched to the improved BW and FCR. FCR is one of the primary indicators used to evaluate the productivity and profitability of the broiler sector. The lower FCR in Zn-supplied groups, either in nano or organic zinc form, indicates that zinc was well utilized by the broilers, increasing the performance index. Also, the augmented feed utilization in broilers given Zn-enriched diets may be because Zn can boost the intestine absorption capacity ***(De Grande et al., 2020),*** leading to an increase in the brush border enzyme activity and nutrient transport systems ***(Awad et al., 2017).*** Additionally, the role zinc plays in DNA synthesis and feed utilization may explain why broilers fed diets supplemented with zinc had increased ADG ***(Li et al., 2019).*** Moreover, it is possible to corroborate the finding that feeding nano zinc oxide at a level of 5 mg Zn/kg caused a significant increase in EEI, as EEI and FCR are inversely dependent on the equation used. This finding agrees with ***El-Husseiny et al. (2012),*** who mentioned that broilers given a diet provided with organic 50% Zn, Mn, and Cu had a significantly adjusted *(P≤ 0.001)* FCR. ***El-Katcha et al. (2017)*** revealed that NZnO addition at 60, 45, or 30 mg/kg diet enhanced the BW, FCR, and PI of broilers. This is also following ***Akhavan-Salamat and Ghasemi (2019)*** and ***El-Haliem et al. (2020),*** who stated that the FCR significantly improved at the level of a 40 mg/kg diet of nano zinc oxide. The highest European production efficiency index (EPEI) was observed in 70 and 90 mg NZnO-supplemented groups ***(Eskandani et al., 2021).***

Furthermore, NZnO at a level of 5 mg Zn/kg (G6) significantly improved the protein efficiency ratio (PER) for finisher diets. These results agreed with ***Abdel-Wareth et al. (2022),*** who noted that the digestibility of crude protein, crude fat, and crude fiber in the broiler was linearly increased by nano zinc oxide (20, 40, and 60 ppm) relative to the control. Among the zinc source-supplemented groups, better growth performance parameters were observed in nano zinc oxide groups, especially G5. Therefore, it was suggested that these birds utilized nano ZnO more effectively. This indicates that nano ZnO was a better source for enhancing the efficacy of nutrient utilization.

The other performance parameters of the broiler, such as livability and mortality, were not markedly impacted by the zinc addition in the diet. This was in line with previously stated reports that the livability or mortality did not significantly change when zinc supplementation was used ***(Zakaria et al., 2017).*** No differences in mortality rates were detected in broilers given diets enriched with 60 or 120 ppm of Zn-methionine ***(Kakhki et al., 2017).*** Also, the broiler mortality rate was not significantly affected by NZnO at a rate of 0, 40, 60, and 100 mg/kg diet ***(Ramiah et al., 2019)***. There was no difference noticed in the livability of chicks received organic or inorganic Zn at the dose of 50 and 60 ppm ***(Chand et al., 2020).*** Blood parameters are employed in poultry and livestock as an indicator of their physiological, pathological, and nutritional status ***(Ogbuewu et al., 2017).*** Zinc promotes the production of SOD, an antioxidant enzyme that protects cells from the destructive effects of free radicals by converting superoxide anions to hydrogen peroxide ***(Niles et al., 2008).*** Besides, research has revealed that zinc increases the synthesis of metallothionein, a cysteine-rich protein that scavenges free radicals ***(Maret, 2000).*** On the other hand, MDA is a consequence of lipid oxidation (LP). Zinc has a crucial role in reduction of the lipid oxidation in the body ***(Zago and Oteiza, 2001).*** Our data showed that nano zinc oxide in G6, followed by G5, and G4, significantly achieved the highest SOD activity compared to others. It was also reported that G4, G5, and G6 significantly achieved the lowest levels of serum MDA compared to G1 and G2. Also, zinc methods have a significant improvement in SOD activity. Various stresses are associated with poultry farming, which lowers the productivity of chickens. Studies have shown oxidative stress to be the primary cause of this stress at the cellular level ***(Surai, 2016).*** Zn deficiency is associated with oxidative stress in poultry, which can be alleviated by vitamin E addition ***(Kraus et al., 1997).*** Because zinc contributes to the synthesis of antioxidant enzymes, it has been proposed that zinc has antioxidant benefits in chickens **(*Saleh et al., 2018)*** and it elevates antioxidant vitamin levels in the blood ***(Onderci et al., 2003).*** Similarly, some investigators, i.e., ***Marreiro et al. (2017)*** mentioned that zinc decreases MDA, indicating the crucial function that zinc plays in reducing lipid peroxidation in the cell membrane. A recent study by ***Abdel-Monem et al. (2021)*** showed that 80 ppm of ZnO-NPs significantly increased the amount of SOD and total antioxidant capacity in chickens and decreased the amount of lipid peroxidation. Besides, ***Hafez et al. (2020)*** revealed that ZnO-NPs decreased the MDA value and increased *(P< 0.05)* the activity of SOD and catalase. Additionally, adding Zn-Met and ZnO-NPs to broiler chickens' diets at a rate of 40 mg/kg may enhance their antioxidant capacity when exposed to high ambient temperatures ***(Akhavan-Salamat and Ghasemi, 2019).*** In the same trend**, *De Grande et al. (2020)*** found that zinc amino acid (ZnAA) at 60 mg/kg was shown to have higher glutathione peroxidase levels and lower serum MDA levels in broilers compared to Zn sulfate. In contrast, ***Fathi (2016)*** found that the addition of 40 mg/kg of micro ZnO did not significantly influence the SOD activity in chickens. ***El-Katcha et al. (2017)*** claimed that the addition of nano zinc (60, 45, 30, or 15 ppm) numerically lowered the blood MDA level in chicks compared to inorganic zinc, while zinc polysaccharide complex (30 or 15 ppm) had no influence on the level of serum MDA. The detected disagreement might be due to differences in health conditions and might be because recent research used high concentrations of NZnO. These results showed that zinc could boost antioxidant status and inhibit LPO (lipid peroxidation) in broilers. The more noticeable effect was achieved by nano zinc oxide in G6, followed by G5 and G4.

HDL is referred to as good cholesterol, it carries cholesterol from the blood into the liver. On the other hand, LDL is referred to as bad cholesterol, It makes up most of the body's cholesterol ***(Avci et al., 2018)***. No significant variation was observed in the cholesterol and triglyceride levels among the different experimental groups. Our data revealed that the nano zinc oxide supplemented group gave the highest HDL level. There was no statistical difference between G6 (nano zinc oxide) in the level of LDL compared with G5, G4, and G3. Our results corroborate the data that confirm the prominent role of zinc on lipid metabolism. ***Al-Bayti et al. (2022)*** verified that zinc has a protective effect on lipid metabolism markers in laboratory rats. Furthermore, studies have shown a correlation between zinc deficiency diets and lower plasma values of triglycerides, LDL, HDL, and total cholesterol. This may result from a reduction in the consumption of fat and calories as well as a decrease in the absorption of dietary lipids ***(Wu et al., 2004)*** and it could be as a result of the fact that zinc is a crucial part of many metalloenzymes needed for lipid absorption and digestion. ***(Al-Daraji and Amen, 2011).*** Like our data, it was conveyed that Zn sources had no impact on the serum cholesterol values in chicks ***(Lü and Combs Jr, 1988). Malcolm-Callis et al. (2000)*** notified that serum cholesterol was not affected by zinc feeding at a rate of 20, 100, and 200 mg zinc/kg. Also, ***Kucuk et***

al. (2008) found that 30 ppm zinc supplementation has no impact on the total cholesterol and triglyceride values. Moreover, using nano zinc treatments at doses of 10, 20, and 40 mg/kg diet, triglycerides were not significantly ($P > 0.05$) altered ***(Fathi et al., 2016).*** Besides, the present data came in harmony with the results of ***Aksu and Ozsoy (2010)*** who reported that organic complexes of zinc, copper, and manganese increased HDL in the blood plasma of chickens. Higher HDL is most likely the result of an increase in fat and calorie consumption following zinc feeding. It was also shown that there was a rise ($P<0.05$) in HDL levels in birds receiving 60 or 90 mg of NZnO/kg feed ***(Ahmadi et al., 2013).*** Nonetheless, plasma cholesterol levels were affected by ZnO given at a rate of 80 mg/day, either on its own or in combining with vitamins or copper ***(Gensler et al., 2002). Herzig et al. (2009)*** shown that the plasma cholesterol of broilers reduced when given a diet rich in zinc. ***Parák and Straková (2011)*** showed this impact when breeding cocks were fed inorganic versus organic zinc. ***Ahmadi et al. (2013)*** showed a decrease in triglycerides, total cholesterol, and LDL ($P > 0.05$) values in chicks who were given a diet with 60 or 90 mg of NZnO. It was reported that female broilers had a significantly lower cholesterol level than males, suggesting that sex is a major factor affecting the plasma cholesterol level of broiler chickens ***(Salim et al., 2012).*** Also, the inconsistent findings in these studies might be due to the period of sample collection within the day, as blood indices vary with the time of the day.

Serum proteins are useful indicators of the condition of bodily cells, tissues, and organs, as well as the metabolism of feed that has been consumed ***(Fuhrman et al., 2004). Walker et al. (1990)*** said that various factors, including the protein level, might be considered when evaluating overall health. The total protein, A/G ratio, and albumin level were significantly higher in the nano zinc supplemented groups (G4, G5, and G6). The globulin level did not vary among the experimental groups. The improvement in total serum protein because of nano zinc oxide supplementation could be illuminated by the pivotal role of zinc in nutrient utilization and protein metabolism. Zinc as previously stated, is a necessary part of the enzymes that synthesize proteins and nucleic acids ***(Maggini et al., 2007).*** These data were proven by ***Feng et al. (2010)***, who discovered that feeding chickens 90 and 140 mg/kg of organic zinc greatly increased the birds' total serum protein. Additionally, feeding Zn supplements to breeder broiler chicks raises their total serum protein levels ***(Al-Daraji and Amen, 2011).*** In contrast, it was shown that the amount or type of zinc did not affect blood total protein or albumin ***(Sarvari et al., 2015).*** Nano zinc supplemented groups (G4, G5, and G6) significantly reduced AST and ALT levels and serum creatinine. The dietary zinc sources didn't reveal significant changes in ALP, LDH, or serum uric acid levels. The collected data is in agreement with ***Ahmadi et al. (2014)*** who mentioned that dietary NZnO (30, 60, 90, or 120 mg/kg diet) significantly *(P<0.05)* decreased blood AST and ALT values compared to basal diet. When broilers were fed 0, 10, 20, and 40 mg/kg of nano zinc oxide, there was no significant change in the activity of alkaline phosphatase (ALP) ***(Fathi et al., 2016). El-Katcha et al. (2017)*** demonstrated that nano zinc (60, 45, 30, or 15 ppm), decreased blood creatinine while having no significant effect on serum uric acid concentration. ***Abdel-Monem et al. (2021)*** illustrated that dietary zinc oxide did not significantly influence serum ALP and uric acid, either added in bulk or nanoform (40 and 80 ppm). Also, nano zinc oxide (0, 20, 40, or 60 mg/kg) exhibited lower serum ALT, AST, and creatinine in broilers ***(Abdel-Wareth et al., 2022).*** Conversely, ***Fathi et al. (2016)*** stated that serum concentrations of ALP level were significantly elevated at 20 mg/kg nano-ZnO. It was demonstrated that serum AST concentrations were not significantly affected by nano zinc (60, 45, 30, or 15 ppm), and there was a numerical increase in serum ALT and ALP levels in broilers ***(El-Katcha et al., 2017).*** *In Ovo* injection and Zn addition (i.e., 0, 60, 0, and 0 mg Zn/egg, 0, 0, 100, and 200 mg Zn/kg basal diets, respectively), revealed no statistical difference in AST and ALT in the blood among the four treatments ***(Kim and Kang, 2022).*** The dietary supplementation of ZnO-NPs at a dose of 40–160 ppm has no alteration in the serum values of AST and ALT ***(Zhang et al., 2022).*** The data indicated that the addition of NZnO caused no obvious negative effects on liver and kidney health conditions, as manifested by unaffected serum activity levels of some enzymes (ALP and LDH) and concentrations of uric acid. Besides, NZnO lessens blood serum ALT, AST, and creatinine levels.

Using nano zinc oxide, whatever the concentration, and zinc methionine significantly gave the highest selling price and net revenue. Besides, the adding of nano zinc oxide in G5 and G6 at the levels of 10 and 5 mg Zn/kg diet, respectively, significantly enhanced economic efficiency compared to chicks in G1 and G2, as well as numerically to chicks in G3 and G4. This improvement was matched with the enhancement in feed conversion and weight gain of broiler chicks. This data agreed with results informed by ***El-Husseiny et al. (2012)*** who noted that chicks fed a diet with 50 or 100% of the organic Zn, Mn, or Cu required by broilers had a greater relative economic efficiency. Additionally, poultry growth performance and economic benefits were enhanced by nano zinc oxide ***(Swain et al., 2016).*** It was claimed that the optimal level of feed additives for broiler chicks to have the optimum growth and economic efficiency be 20 mg/kg of nano ZnO ***(Zhao et al., 2014).*** When compared to ZnO, the addition of nano zinc oxide (40 mg Zn/kg diet) resulted in the best return, selling price and cost savings ***(Alian et al., 2022).*** One other thing is that the net profit is unaffected by substituting nano Zn for a traditional zinc source at levels of 0.0, 25, 50, 75, and 100%. ***(Asheer et al., 2018).***

Conclusion

Our results can help broiler producers enhance the performance of their birds. Broiler producers will have more financial benefits from feed additives. The nano zinc oxide, whatever the concentration in G4, G5, and G6, will achieve the best performance, enhance antioxidant activity, inhibit lipid peroxidation, improve lipid profiling, and augment liver and kidney functions in chicks. All positive impacts were more prominent in the NZnO (G6) group. Therefore, applying nano zinc oxide (5 mg Zn/kg diet) is an innovative feed additive in the broiler industry.

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Statements & Declarations

Ethical Approval.

All operations have been authorized by the Faculty of Agriculture's Animal Care and Use Committee at Suez Canal University, as shown by the permission number (4/2024).

Authors' contribution.

Each author planned the study project and wrote the manuscript's draft.; HS finished the experiments; HS measured the study parameters, and HA wrote the manuscript and conducted the statistical analysis.

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Data Availability Statement

The data produced by this experiment is included in this article.

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مكملات الزنك النانوية مقارنة بمصادر الزنك الأخرى: التأثيرات على الاداء وتركيزات مصل الدم والتقييم الاقتصادي في بداري التسمين

حماده صلاح صابر محمد[1]، هبه عليان عبدالرحمن[2]
[1] قسم الانتاج الحيوانى كلية الزراعة [2]قسم التغذية والتغذية الأكلينكية كلية الطب البيطرى الاسماعلية 22122 جامعة قناة السويس جمهورية مصر العربية
هبه عليان عبدالرحمن (heba.alian@vet.suez.edu.eg)

كان الهدف من الدراسة الحالية هو تقييم مدى تأثير مصادر الزنك المختلفة على النمووتركيزات مصل الدم والتقييم الاقتصادي في بداري التسمين. تم توزيع الكتاكيت "كوب" بعمر يوم واحد (ن = 192) بمتوسط وزن أولي 44.10 جرام عشوائيا إلى 6 مجموعات. تم تزويد المجموعات الأولى والثانية والثالثة بأكسيد الزنك غير العضوي وكبريتات الزنك غير العضوية أحادي الهيدرات وميثيونين الزنك العضوي على التوالي بمستوى 100 مجم زنك / كجم عليقة. تم تزويد المجموعات الرابعة والخامسة والسادسة بأكسيد الزنك النانوي (NZnO) بمستوى 20 و10 و5 مجم زنك / كجم عليقة على التوالي. أظهرت الدراسة أن أكسيد الزنك النانوي عند مستوى 5 ملجم زنك / كجم (G6) حقق تحسنًا كبيرًا ($P < 0.05$) في وزن الجسم النهائي وزيادة وزن الجسم التراكمية ونسبة تحويل العلف وكفاءة التحويل الغذائي. زاد أكسيد الزنك النانوي (G6) من نشاط إنزيم أكسيد الفائق ديسميوتاز (SOD) ومستويات HDL (البروتين الدهني عالي الكثافة) إما معنويا ($P < 0.05$) مقارنة بـ G1 و G2 و G3 و G4 أو عدديًا مع G5. أدي إضافة أكسيد الزنك النانوي إلى تقليل مستويات مالونديالدهيد (MDA) و(ALT) و (AST) والكرياتينين في مصل الدم.
حقق أكسيد الزنك النانوي في G5 و G6 أفضل النتائج بشكل معنوي في تعزيز الكفاءة الاقتصادية ($P < 0.05$).حققت مجموعات أكسيد الزنك النانوي أفضل أداء وعززت نشاط مضادات الأكسدة وعززت تحليل الدهون وحسنت وظائف الكبد والكلى. كانت النتائج الإيجابية أكثر وضوحًا في G6 لذلك، فإن استخدام أكسيد الزنك (5 ملغ زنك/كجم عليقة) يعد من إضافات الاعلاف الواعدة الجديدة في صناعة الدجاج اللاحم.

الكلمات المفتاحية: مضاد الأكسدة، الدجاج اللاحم، اقتصادي، نانو زنك، أداء.